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DESCRIPTIVE PETROGRAPHY OF ROCKS DREDGED OFF THE COAST OF CENTRAL CALIFORNIA

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Introduction

Several different kinds of igneous and sedimentary rocks were collected by the California Academy of Sciences while investigating the geology of the continental slope off the coast of central California. By far the largest number consisted of fine-grained fossiliferous siltstones which contain both diatoms and foraminifera. The next most abundant were the volcanic rocks, mainly rhyolite, andesite, and basalt. Quartz diorite was the only plutonic rock collected and it constituted only a minor part of the many samples obtained during the course of the investigation. Representative material was chosen from the various stations and the following report is the result of study of thin sections as well as hand specimens. Localities are recorded by station number, the details of which may be found on pp. 334–343 of the preceding report by G D. Hanna (1952).

There were essentially four kinds of sedimentary rocks collected. They are fossiliferous siltstones, sandstones, phosphorites, and tuffs. Siltstones were collected at stations 7, 14, 19, 25, 38, 51, 54, 56, 62, and 64; sandstone at stations 2 and 11; phosphorites at stations 12, 25, 45, 56, and 62; and tuff at stations 2, 25, and 29. Several of the siltstone samples collected at stations other than those listed for phosphorites, are slightly phosphatic, but not sufficiently to be classed with the phosphorites.

The plutonic rocks are very uniform in character and composition. They are biotite-quartz diorite and were collected at stations 2, 7, 10, 32, and 54. There is, however, considerable variation in the types of volcanic rocks collected, both as to composition and texture. Basalt samples were collected at stations 25, 27, 29, 32, and 38; andesites at stations 2 and 7; and rhyolites at station 5 only.

The phosphorites and phosphatized sedimentary and volcanic rocks are of considerable interest, especially economic interest. Not only have some of the siltstones been more or less completely phosphatized, but several specimens of tuff and basalt have also been partly phosphatized. One specimen of basalt (station 29) is phosphatic to a depth of ⅛ inch. The interior of the same specimen is slightly phosphatic, but not anywhere as much as the rim. Specimens of tuff and tuff breccia from stations 2 and 25 have been partly phosphatized.

A study of the phosphorites and partly phosphatized rocks indicates somewhat the extent to which phosphatization has taken place, but does not indicate the lateral extent of the process nor the size and shape of the phosphate bodies. The latter, however, can only be determined through careful and systematic sampling of those areas where phosphorites and phosphatized rocks were found.

Plutonic Rock

Biotite-Quartz Diorite: The biotite-quartz diorite is typically coarse-grained, equigranular, massive, and slightly gneissoid. Few of the specimens showed minor amounts of brecciation. On the weathered surface, the rock is unequally colored with limonite. Quartz and plagioclase are the essential minerals. Biotite is present in all specimens, whereas hornblende occurs only sporadically. The quartz is glassy and the feldspar is dull white.

Microscopical Characteristics: Under the microscope the biotite-quartz diorite has a hypiodiomorphic-granular texture. The grain size ranges from 1 to 5 mm. for plagioclase; 1 to 2 mm. for quartz; and up to 3 m. for biotite. The plagioclase ranges in composition from basic oligoclase (An_{25}) to acid andesine (An_{35}). It occurs in subhedral crystals and irregularly shaped grains showing well developed albite and carlsbad twinning and poorly developed pericline twinning. Zoning is not common, though present in the quartz diorite from station 25. Alteration to kaolin and calcite is common, more so at the interior of the crystals than the exterior. Both orthoclase and microcline are present in limited amounts, especially in the form of anhedral crystals which have been more or less altered to kaolin and sericite.

Quartz, on the other hand, generally appears as glassy and slightly clouded anhedra. In a few specimens it shows strain shadows and contains numerous curving hairlines of sub-microscopic, black inclusions.

Although both biotite and hornblende are present, biotite is the commonest ferromagnesian mineral in the rock. It usually occurs in dark brown pleochroic plates and irregular crystals. Alteration to dark green chlorite is common, especially at stations 7 and 25. Hornblende is in dark green, pleochroic, subhedral crystals. They are also partly altered to chlorite.

Sphene, zircon, apatite, and magnetite occur sporadically as inclusions in the other minerals.

In so far as mineral composition is concerned, the biotite-quartz diorite contains, on the average, the following:

Plagioclase	40 to 60 per cent
Quartz	35 to 50 per cent
Biotite	5 to 10 per cent

The biotite-quartz diorite collected in the deep waters off the coast of central California very closely resembles the quartz diorite exposed on south Farallon Islands (Hanna, 1951) and along the coast from Montara Mountain (Lawson, 1895) to Point Sur (Trask, 1927, and Reiche, 1937).

Volcanic Rocks

Three kinds of volcanic rocks were collected and examined microscopically. They are, rhyolite, andesite, and basalt. There is far more variation in the basalts than either the rhyolites and andesites. Some of the basalts contain olivine while others are devoid of this mineral. Also, there appears to be a wider distribution of basalt as indicated by the amount of this material collected at the various stations.

Rhyolite: Rhyolites were collected only at station 25. In hand specimen, the rhyolite is a dense, hard, fine-grained porphyritic rock varying in color from medium gray, through dark brownish-gray to chocolate brown.

Microscopical Characteristics: Under the microscope they are porphyritic in which phenocrysts of quartz, orthoclase, and plagioclase are enclosed in a microcrystalline groundmass of partly devitrified glass. In several of the specimens showing less devitrification, fluidal banding and flow lines are distinctly visible. Sanidine is the potash feldspar. An occasional angular crystal of anorthoclase can be found. The sanidine normally occurs in euhedral and subhedral crystals with or without carlsbad twinning. Alteration to kaolin is common, especially along fractures. Some of the fractures in a few of the more altered phenocrysts are filled with an aggregate of small quartz grains, apparently secondary.

Quartz is an abundant mineral, and occurs in the groundmass and as anhedral crystals and corroded grains. It is glassy in appearance and oftentimes shows strain shadows.

TABLE 1

Areal Distribution of Rock Types Examined Microscopically

Station	Plutonic Rock	Rhyolite	Andesite	Basalt	Siltstone	Sandstone	Phosphorite	Pyroclastic
2	3	5	3	.	.	1	.	1
7	1	.	1	.	2	.	.	.
10	2	.	.	.	.	.	.	.
11	.	.	.	.	.	2	.	.
12	.	.	.	.	.	.	3	.
14	.	.	.	.	3	.	.	.
19	.	.	.	.	1	.	.	.
25	.	.	.	2	1	.	.	2
27	.	.	.	1	.	.	.	.
29	.	.	.	1	.	.	.	1
32	1	.	.	4	.	.	.	.
38	.	.	.	1	1	.	.	.
45	.	.	.	.	.	.	3	.
51	.	.	.	.	1	.	.	.
54	1	.	.	.	2	.	.	.
56	.	.	.	.	4	.	2	.
62	.	.	.	.	8	.	1	.
64	.	.	.	.	4	.	.	.
Totals	8	5	4	9	27	3	9	4

STATIONS FROM WHICH SAMPLES WERE SELECTED FOR DETAILED STUDY*

Sta. No.	Depth fathoms	Nature of specimens
2	57–50	3 in place, 10 pebbles
7	124–90	1 in place, 3 pebbles
10	34	2 in place
11	74	2 pebbles
12	218–100	3 phosphorite
14	126–70	3 erratic
19	68–70	1 in place
25	480–450	2 in place, 3 perhaps erratic
27	600–500	1 in place
29	440–540	2 in place
32	1000–700	4 in place, 1 erratic
38	690–800	1 in place, 1 erratic (?)
45	600–400	3 phosphorite
51	180–80	1 in place
54	45–55	2 in place, 1 erratic
56	400–200	6 in place
62	1150–1000	9 in place
64	1100–1000	4 in place

* In this table an attempt has been made to indicate whether the material was in place on the sea bottom, but obviously this is often uncertain.

The plagioclase varies in composition from acid to basic oligoclase (An_{15} to An_{25}). It usually occurs in subhedral crystals showing both carlsbad and albite twinning. An occasional crystal showing pericline twinning is present. Alteration to kaolin is more pronounced in some rocks than in others.

Biotite is the only ferromagnesian mineral present in the rhyolites. It occurs in subhedral crystals which show, in some sections, considerable alteration. The unaltered biotite is dark greenish-brown and strongly pleochroic. In several sections the biotite has been altered to pale green chlorite. In the outer part of each altered biotite crystal one can find a narrow black zone of magnetite.

For the most part, the groundmass is composed of a partly devitrified glass, dark to medium-brown in color. Flow banding and fluidal structures are still evident. (See plate 15.) In one section, the glass is completely devitrified and consists almost wholly of a microcrystalline aggregate of quartz and feldspar grains so arranged as to indicate the original flow banding.

Andesite: Four specimens of andesite were collected from stations 2 and 7. In hand specimen, they range in color from dark greenish-gray to dark greenish-brown. The andesite, in general, is a hard, fine-grained, porphyritic rock containing distinct crystals of dull white feldspar firmly held in a fine-grained, semi-glassy groundmass. Ratio of groundmass to phenocrysts is approximately 10 to 1.

Microscopical Characteristics: The rock has a well developed porphyritic texture which shows phenocrysts of plagioclase and orthoclase set in a semi-crystalline groundmass. One specimen from station 2 is somewhat fragmental and appears to be an andesite breccia. The plagioclase is variable in composition, ranging from acid to intermediate andesine (An_{35} to An_{40}). It generally occurs as euhedral crystals, occasionally as subhedral and anhedral crystals. Albite, carlsbad, and pericline twinning are common. Inclusions of glass, sphene, epidote, and even chlorite are present in the plagioclase. Calcite and kaolin are the two alteration products, but a few crystals of basic oligoclase were found partly altered to epidote.

The groundmass plagioclase is usually in the form of untwinned microlitic laths scattered at random throughout the sections.

Orthoclase, when present, is in the form of subhedral crystals partly altered to kaolin and sericite.

Quartz is present in only those andesites collected at stations 2 and 7. It occurs, however, in small amounts, usually in well rounded grains and in fine-granular aggregates, especially in those areas where the groundmass glass has been most thoroughly devitrified. All ferromagnesian minerals, including hornblende and augite, have been completely altered to epidote and chlorite.

For the most part, the groundmass consists essentially of more or less completely devitrified glass which still retains some of its original fluidal structures. Secondary minerals include: epidote, chlorite, calcite, limonite, kaolin, and sericite.

Basalt: Of all the volcanic rocks collected, basalt is by far the most widespread in distribution. It was collected at five separate stations, two of which are Pioneer and Mulberry Seamounts.

In hand specimen the basalt is vesicular, black to grayish-black in color, fine-granular, and porphyritic. The feldspar phenocrysts are dark and glassy, while the olivine phenocrysts are dark green and the augite black. The vesicles are either filled or empty. The filling is chalcedony, chloropal, and calcite.

Microscopical Characteristics: Under the microscope the basalts have a porphyritic and sub-ophitic texture in which phenocrysts of feldspar are enclosed in a groundmass of lath-shaped feldspar and intersertal augite. Basic glass is rare, though often very dark due to the presence of dusty magnetite.

The essential minerals are basic plagioclase and augite. The plagioclase ranges in composition from intermediate to basic labradorite (An_{60} to An_{70}). The feldspar phenocrysts are more basic than the feldspar in the groundmass. Both carlsbad and albite twinning are common, and zonal structures are found, especially in the euhedral phenocrysts. Inclusions of dark brown glass are common. Few of the crystals are altered to calcite and kaolin. The phenocrysts are much more altered than the groundmass laths.

The clinopyroxene is augite. At stations 25, 32, and 38, basalt specimens were collected which contain titaniferous augite. In all cases, however, the augite is in the form of euhedral and subhedral crystals, both occurring as phenocrysts and as intersertal grains between the feldspar laths.

The titaniferous augite is pale violet in color and exhibits very strong dispersion. Although usually quite fresh in most rocks and sections, several sections showed it as having been altered in part to pale green chlorite with separation of magnetite (see plate 16 which shows a euhedral crystal of titaniferous augite rimmed with pale-green chlorite speckled with cubes and octahedra of magnetite). Other augite is colorless, and, too, has been altered partly to chlorite and almost colorless serpentine.

Olivine is not present in all basalts. When present, however, it is more or less completely altered to pale green serpentine and golden-yellow iddingsite. The unaltered olivine occurs in euhedral crystals showing prismatic faces and pyramidal terminations. Few of them have corroded borders. Inclusions of chromite are common, especially in the serpentinized crystals.

In addition to plagioclase and augite as groundmass constituents, there is also some dark brown glass which derives its dark color from black, dusty particles of magnetite.

Secondary minerals include: serpentine, iddingsite, chlorite, calcite, kaolin, limonite, chalcedony, and chloropal.

Sedimentary Rocks

Sedimentary rocks of various types were collected from 15 stations (2, 7, 11, 12, 14, 19, 25, 29, 38, 45, 51, 54, 56, 62, and 64). They include siltstone (fossiliferous and non-fossiliferous), sandstone, phosphorite, and tuff. To further classify them according to mode of origin, the siltstones and sandstones are clastic; the phosphorites are chemical, and the tuffs and tuff breccia are pyroclastic. The phosphorites and phosphatized rocks are perhaps of much more interest than any other sedimentary rock.

Clastic

Siltstone: In general, the siltstones are very fine-grained, buff to gray colored rocks. Bedding is poorly developed, and only visible in one or two specimens. They all contain circular conical holes, caused by marine boring organisms. All of the siltstones sectioned are hard and firmly cemented with silica and calcium carbonate. Some of them are fossiliferous and contain tests of diatoms and foraminifera. Specimens collected from stations 25, 51, and 62 are slightly tuffaceous and contain small angular fragments of pumice as well as glass shards.

Microscopical Characteristics: Under the microscope, the siltstones appear to range from massive siliceous shales to ordinary siltstones. They are all very fine-grained and appear to consist of angular grains of quartz, orthoclase, oligoclase, biotite, and pumice fragments enclosed in a much finer grained groundmass of silica, calcite, and clay particles. As previously stated, bedding is poorly developed. Scattered indiscriminately throughout the rocks are ovid-shaped bodies of emerald green mineral which resembles glauconite, but owing to its much weaker pleochroims it is tentatively called chamosite. Present in these green bodies are black cubic crystals of magnetite.

An occasional plate of pale green chlorite can be found. The pumice fragments and the glass shards have been largely devitrified and now present a characteristic salt and pepper effect. Specimens collected from stations 7, 14, 51, 56, 62, and 64 show some degree of phosphatization. The phosphatic material is yellowish to deep yellow-brown in color. It is isotropic and traversed by numerous conchoidal fractures. The phosphatic material is not evenly distributed throughout the rock, but seemingly localized in irregular patches where it acts somewhat as a cementing material for the detrital grains. In a few of the sections, there occurs a narrow, dark brown rim immediately surrounding the mineral grain which is enclosed in the phosphatic material. Also, in some of the tuffaceous siltstones, the pumice fragments are more or less completely changed over to the phosphatic material.

Scattered throughout the siltstones are tests of diatoms and foraminifera. The foraminifera tests are composed largely of calcite, while the diatoms are chalcedony. Some of the foraminifera have been partly phosphatized.

The groundmass, for the most part, is a mixture of chalcedony, calcite, and clay. Several of them contain more calcite than others, while some are rich in clay and chalcedony.

Sandstone: Sandstone specimens were collected at stations 2 and 11. The specimen from station 2 is a brecciated, gray, hard, firmly cemented sandstone made up of angular grains of quartz and feldspar firmly held in a chalcedonic-silica cement. The grains range in size from .5 mm to 2 mm. Specimens from station 11 are slightly finer grained than those from station 2. They, too, are gray in color and contain, besides quartz and feldspar, considerable dark brown biotite. The grains range in size from .5 mm. to 1 mm.

Microscopical Characteristics: Under the microscope the sandstones appear to be composed of rounded and angular grains of quartz, basic andesine, orthoclase, dark brown biotite, and muscovite set in a silica matrix. The feldspar is partly altered to kaolin and sericite and the biotite to dark green chlorite. The quartz occurs commonly in rounded and angular grains. Many of them are fractured and recemented with calcite and chalcedony. The brecciated sandstone from station 2 contains the following mineral composition:

Quartz	35 to 45 per cent
Andesine	25 to 30 per cent
Orthoclase	5 to 10 per cent

Chemical Sedimentary Rocks

Phosphorite: Most of the phosphorite specimens are either dark chocolate brown or brownish-gray in color. They were collected from stations 12, 45, 56, and 62, along with other phosphatized siltstones. They all contain angular and rounded mineral grains. Some grains are glassy, others dull, but a majority of them are well rounded, especially the dull ones. Rock fragments, too, are present in limited amounts. Several specimens of phosphatized siltstone from stations 56 and 62 were found to contain 50 per cent or more phosphatic material. Their grain size is quite small, and they contain, in addition to quartz and feldspar, angular fragments of andesite and tests of diatoms and foraminifera which, too, have been largely phosphatized.

Microscopical Characteristics: Microscopically, the phosphorites and phosphatized siltstones vary considerably in mineralogical composition and texture. The phosphorites from station 56 consist of pellet phosphorite, phosphatic material, oolites, and detrital grains of quartz, feldspar, biotite, and oval-shaped grains of chamosite. In all the phosphorites, the oolites and pellets are somewhat widely separated (see plate 19, figure 2). Some of the pellets and oolites have neuclei of phosphatic material or a grain of quartz or feldspar. Wherever a concentric structure exists, it is usually confined to the exterior of the oolite. In a few places the chamosite surrounds and partly fills cavities in some of the pellets of phosphorite. The phosphatic material is largely collophane with a refractive index of 1.610. It is isotropic and ranges in color from yellowish to yellow-brown.

PYROCLASTIC ROCKS

Rhyolite Tuff Breccia: This is a dense, fairly hard, fine-grained fragmental rock. It is dark gray in color and consists of angular fragments of quartz, feldspar, pumice, and rhyolite firmly cemented in a dense, dark greenish-gray, fine-grained groundmass. The mineral grains range in size from .5 mm. to 2 mm.

Microscopical Characteristics: Under the microscope one can easily recognize the fragmental nature of the rock. It contains angular grains of orthoclase, plagioclase, quartz, pumice, and rhyolite firmly held in a groundmass of devitrified glass. The orthoclase is more or less altered to kaolin. It shows a well developed carlsbad twin in those grains which are incompletely altered. The plagioclase, too, is very highly altered to kaolin, but still one can make out the albite and carlsbad twinning. Although no definite composition can be assigned to the plagioclase, it appears to lie near intermediate oligoclase. Quartz is glassy, and occurs as angular and rounded grains, and as granular intergrowths with feldspar.

The groundmass is a fine-grained, devitrified glass which contains angular fragments of pumice and rhyolite. Flow banding may still be seen in those places where devitrification is less complete.

Among the secondary minerals, chlorite and kaolin are very common. The chlorite is pale green in color and exhibits beautiful ultra-blue and violet interference colors.

Basic Tuff: This is a fragmental rock with a mottled, grayish-brown color. On the weathered surface it is light brown in color. It contains angular fragments of pumice, minerals, and basalt held in a fine-grained, dark brown groundmass. The mineral fragments range in size from 1 mm. to 8 mm. The rock fragments are somewhat larger.

Microscopical Characteristics: The rock is decidedly fragmental, and is composed of angular fragments of plagioclase, augite, and basalt firmly held in a groundmass of phosphatized basic glass. The plagioclase ranges in composition from basic andesine (An_{45}) to acid labradorite (An_{50}), and occurs in partly altered, rounded and angular grains. Both carlsbad and albite twinning are common.

Augite is another common mineral. It is either colorless or pale pinkish, and occurs in rounded or subhedral grains. Alteration to chlorite is rare. However, one can find several angular and rounded grains surrounded by a narrow rim of dark brown phosphatic material (see plate 19, figure 1). In addition, an occasional feldspar grain and even small fragments of basalt have rims of phosphatic material. The degree of phosphatization was probably more intense in the case of this tuff than in some of the siltstones. Not only are the basalt fragments surrounded by a phosphatic rim, but the process went so far as to destroy the glassy groundmass in the basalt. Besides the phosphatic material, there are several round grains of emerald-green chamosite enclosing cubes and octahedra of magnetite.

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EXPLANATION OF PLATES

PLATE 15

Figure 1. Rhyolite. Showing subhedral crystal of sanidine (F) and a rounded grain of quartz (Q) held in a groundmass of partly devitrified glass (Gl.). Note fluidal banding and structures. From station 2. Magnification 70X. Plain light.

Figure 2. Basalt. Phenocryst of titaniferous augite (A) surrounded by rim of chlorite speckled with black magnetite and labradorite (F) enclosed in a dark groundmass of basic glass. From station 25. Magnification 70X. Plain light.

PLATE 16

Figure 1. Basalt, showing large subhedral phenocryst of titaniferous augite (A) surrounded by euhedral laths of labradorite. All enclosed in a groundmass of dark basic glass. From station 25. Magnification 70X. Plain light.

Figure 2. Slightly phosphatized fossiliferous siltstone, showing foraminifera and diatoms enclosed in a fine-grained groundmass of chalcedony, calcite, clay, and collophane. Dark coloration due to limonite. From station 45. Magnification 70X. Plain light.

PLATE 17

Figure 1. Fossiliferous siltstone, showing diatoms enclosed in a fine-grained matrix of clay, chalcedony, and calcite. Minor amounts of quarts and feldspar are also present. From station 64. Magnification 70X. Plain light.

Figure 2. Phosphatized siltstone, showing angular grains of quartz (Q), orthoclase (F), and pumice (Pu) inclosed in a phosphatized (Po) groundmass which consists almost wholly of collophane. From station 45. Magnification 70X. Plain light.

PLATE 18

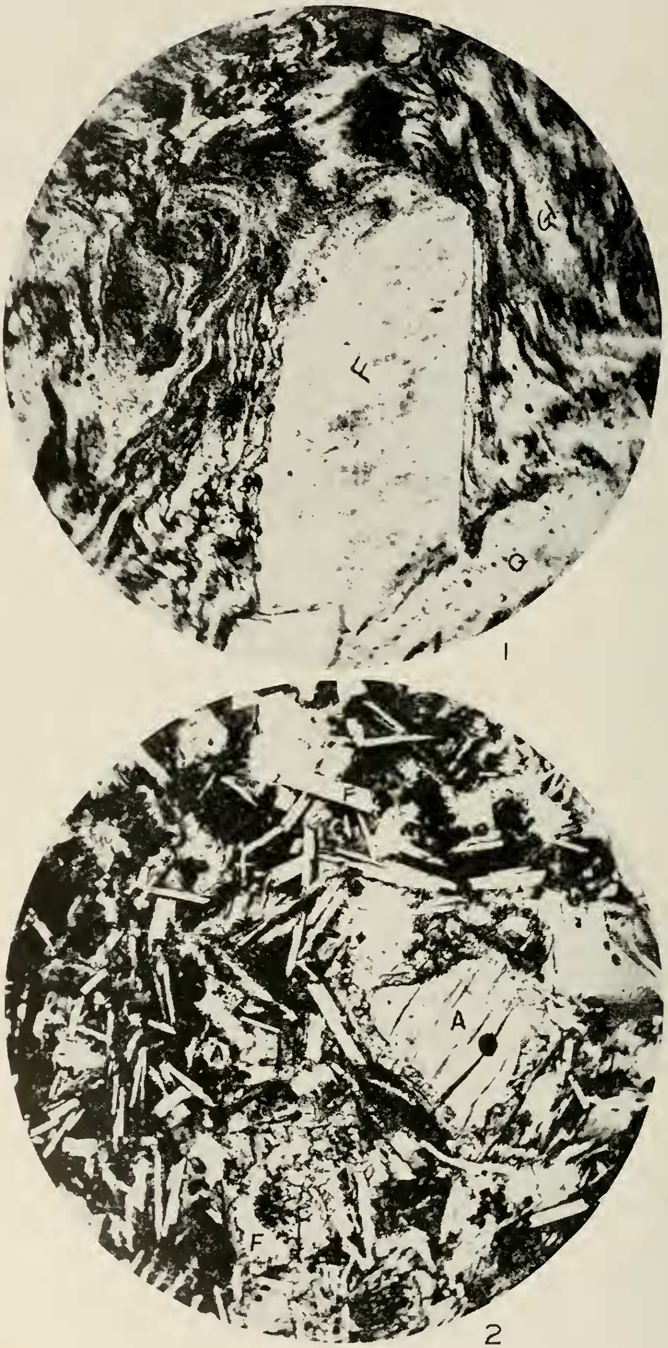
Figure 1. Phosphorite. Angular and rounded grains of orthoclase (F) and quartz (Q) are surrounded by phosphatic material (Po). Note concentric structure in oolite. All dark borders are phosphatic material. Groundmass is essentially collophane. From station 56. Magnification 70X. Plain light.

Figure 2. Collophane. Phosphatized bone from station 56. Magnification 70X. Plain light.

PLATE 19

Figure 1. Phosphatized basic tuff. Note dark border of phosphatic material surrounding euhedral crystals of augite (A) and angular grains of feldspar (F). Groundmass is largely phosphatized basic glass. From station 25. Magnification 70X. Plain light.

Figure 2. Phosphorite. Angular and rounded grains of orthoclase (F), quartz (Q), and pumice (Pu) are surrounded by phosphatic material (Po). Concentric structure is well shown in several grains. Groundmass is essentially phosphorite. From station 56. Magnification 20X. Plain light.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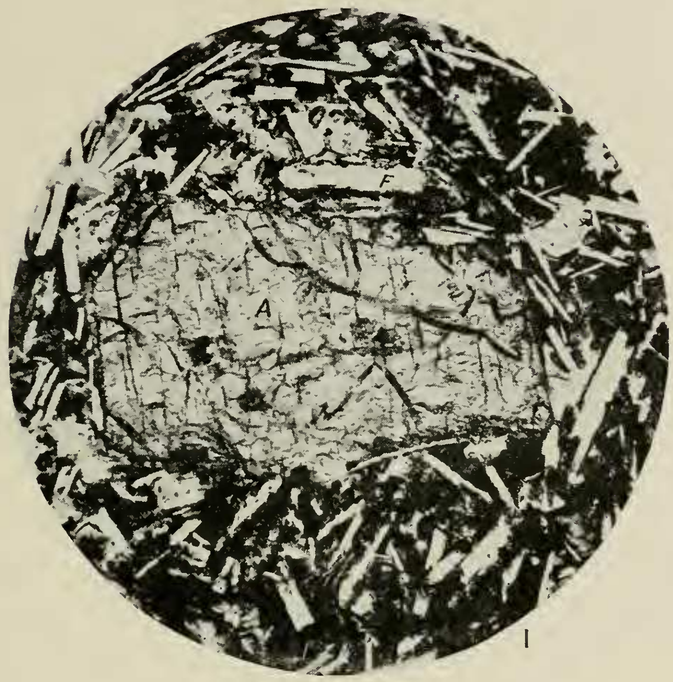

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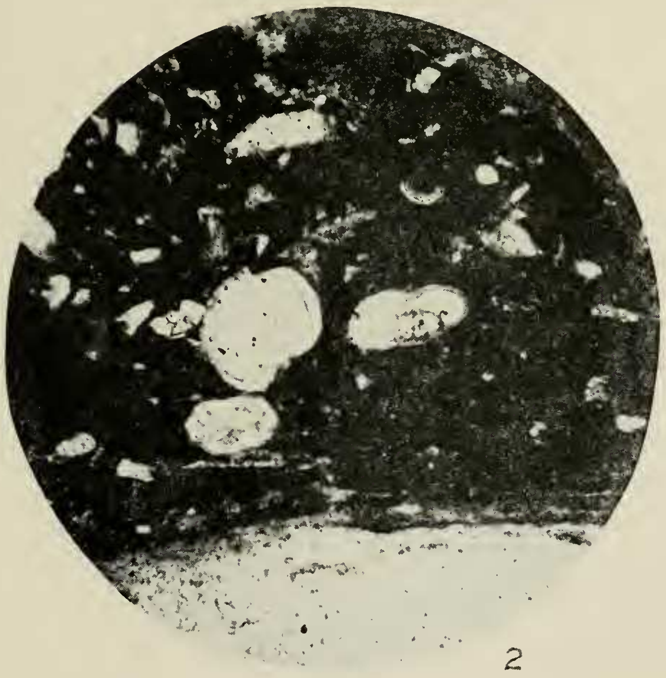

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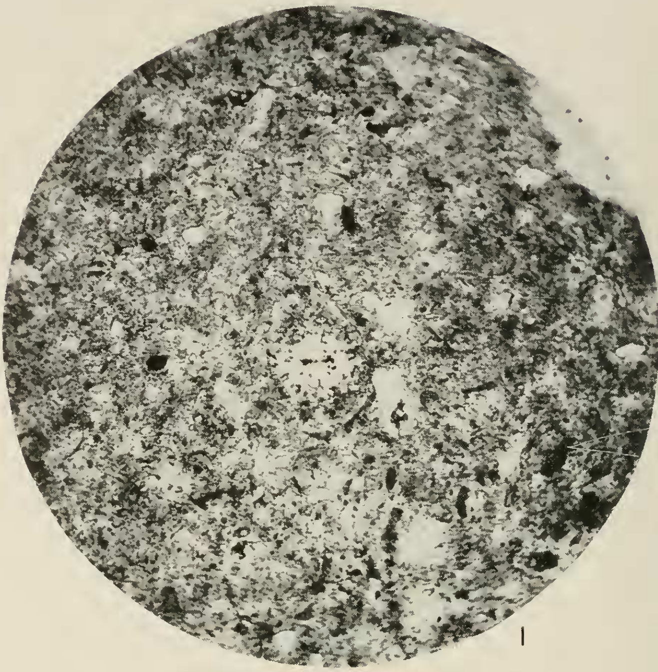

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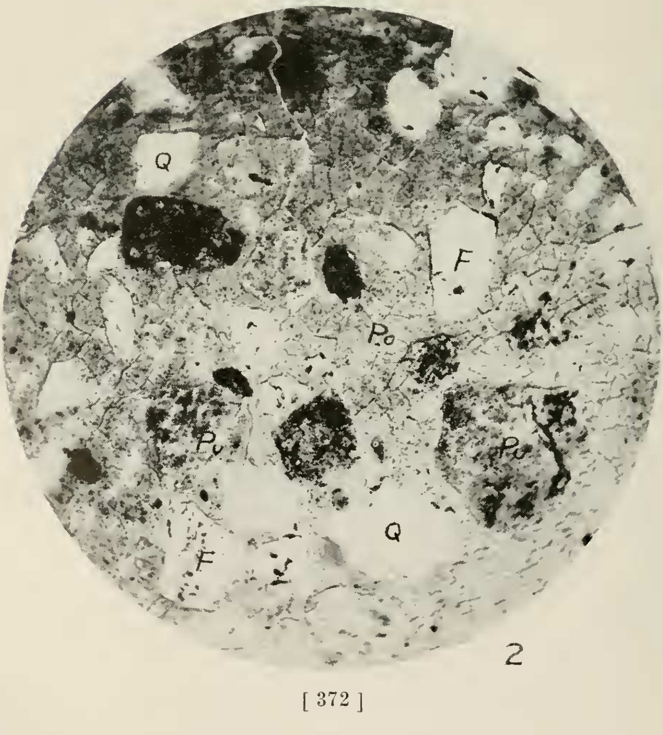

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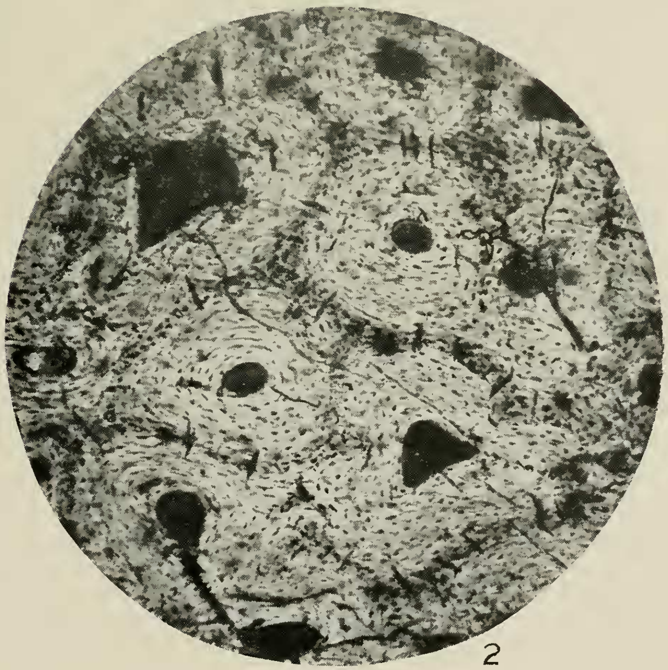

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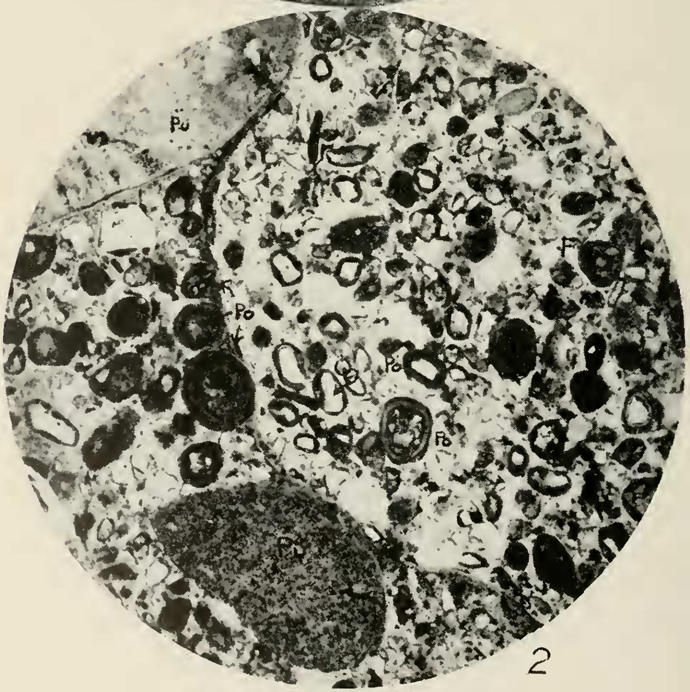

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